

# **Analysis of Observations from the Coastal Mixing and Optics Moored Array**

Steven J. Lentz

Physical Oceanography Department, MS #21

Woods Hole Oceanographic Institution, Woods Hole, MA 02543

phone: (508) 289-2808 fax:(508) 457-2181 email: [slentz@whoi.edu](mailto:slentz@whoi.edu)

R. K. Shearman

Physical Oceanography Department, MS #21

Woods Hole Oceanographic Institution, Woods Hole, MA 02543

phone: (508) 289-3346 fax:(508) 457-2181 email: [rshearman@whoi.edu](mailto:rshearman@whoi.edu)

Award Number: N00014-1-0140

<http://uop.whoi.edu/pub/uopcmo.html>

## **LONG-TERM GOALS**

Our long-term goal is to identify and understand the dominant vertical mixing processes influencing the evolution of the stratification over continental shelves.

## **OBJECTIVES**

We want to understand the processes influencing the observed evolution of the stratification over the New England shelf during the Coastal Mixing and Optics program. We are particularly interested in the relative contributions of local, one-dimensional mixing processes, such as wind forced mixing, cooling, and tidal mixing versus three dimensional advective effects.

## **APPROACH**

Analysis of observations from a moored array of instruments deployed at a mid-shelf location in the Mid-Atlantic Bight from August 1996 through June 1997. The deployment spanned the destruction of the thermal stratification in fall and redevelopment of the stratification in spring and included currents, temperature and conductivity measurements spanning the water column and meteorological measurements to estimated surface fluxes. Additionally we plan to do some simple modeling to aid in interpreting the observations.

## **WORK COMPLETED**

A manuscript characterizing the temperature/salinity variability and the processes responsible for that variability during CMO has been completed and submitted to the *Journal of Geophysical Research*. Two manuscripts characterizing the subtidal current variability and the associated dynamics, and the tidal and supratidal current variability are nearly completed.

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>30 SEP 2001</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2001 to 00-00-2001</b>	
4. TITLE AND SUBTITLE <b>Analysis of Observations from the Coastal Mixing and Optics Moored Array</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Physical Oceanography Department, MS #21,,Woods Hole Oceanographic Institution,,Woods Hole,,MA, 02543</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT <b>Our long-term goal is to identify and understand the dominant vertical mixing processes influencing the evolution of the stratification over continental shelves.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>5</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## RESULTS

The seasonal thermocline was well established on the New England shelf in August. The destruction of the seasonal thermocline during the fall resulted in an essentially unstratified water column in late November and early December. During the winter, the water column was stratified near the bottom due to the onshore movement of warm, salty, shelf-slope front water. In spring, stratification developed in the upper water column due to both the reestablishment of the seasonal thermocline and the presence of buoyant low-salinity water in the upper 20 m. Four processes contributed to these variations. (1) The breakdown of stratification was primarily due to wind forcing, not surface cooling, and occurred in four discrete steps associated with westward, along-coast wind stress events. Eastward wind stresses of similar magnitude did not reduce the stratification. (2) The on-offshore movement of the foot of the shelf-slope front throughout the deployment was, at least in part, wind-driven. The water column at mid shelf remained stratified throughout most of the winter due to the onshore displacement of shelf-slope front water forced by anomalously strong and persistent eastward wind stresses. (3) The gradual redevelopment of the thermocline, beginning in April, was primarily a one-dimensional response to the increasing surface heat flux. (4) Stratification in early April and throughout May was substantially enhanced by low-salinity water associated with river runoff from southern New England, notably the Connecticut River. This low-salinity water was driven eastward and offshore by upwelling-favorable wind stresses.

Tidal, inertial and higher-frequency current variability constituted a substantial fraction of the total current variability on the New England shelf. Semidiurnal tidal amplitudes were approximately 11 cm/s, diurnal tidal amplitudes were approximately 5 cm/s. The vertical structure of both diurnal and semidiurnal tidal variability was nearly barotropic. Approximately 10 m above the bottom (mab), tidal current amplitudes decreased rapidly towards the bottom, consistent with the presence of mixing in a tidally-driven bottom boundary layer. Semidiurnal tidal variability increased substantially in the onshore direction, from amplitudes of approximately 8 cm/s at the offshore site to 13 cm/s at the inshore site. Baroclinic tides were evidently small. The barotropic vertical mode (EOF) explained about 90% of the semidiurnal variability, while the first baroclinic mode explained only 7%. The vertical mode analysis does not identify baroclinic tidal variability that is in phase with barotropic variability. There is potentially a substantial baroclinic tide that exists in phase with the barotropic tide.

Inertial variability during CMO was vigorous, but episodic. The standard deviation of currents in the inertial frequency band (1.05–1.6 cpd) were around 5 cm/s, however, peak currents during bursts of inertial variability ranged as high as 50 cm/s. The vertical structure in inertial variability was primarily contained in the first baroclinic mode. Unlike tidal variability inertial variability increased in the offshore direction. Interestingly, rotary spectra indicated two distinct peaks in inertial variability; one at the inertial frequency (1.3 cpd) and one at a subinertial frequency (1.2 cpd). During the fall (August through December 1996), inertial variability occurred at the subinertial frequency, and during the spring, inertial variability occurred at the inertial frequency. The shift to a subinertial frequency during the fall was caused by the presence of large ( $0.05f$ , where  $f$  is the local planetary vorticity) anticyclonic relative vorticity in the subtidal currents. The relative vorticity adds to the planetary vorticity, changing the local *in-situ* rate of rotation, and yields an effective Coriolis (inertial) frequency that is the planetary plus the relative vorticity.

Subtidal current variability during CMO was large with standard deviations of approximately 10 cm/s. Subtidal current variability was polarized along-isobath and highly correlated with the along-coast

component of wind stress. Subtidal variability with periods of 2 to 10 days was dominated by eastward/westward along-isobath current events in response to upwelling/downwelling favorable along-coast wind stress events. As noted above, the downwelling favorable events also coincided with a reduction in stratification. The mean and low-frequency subtidal currents (monthly to seasonal time scales) were westward and offshore at nearly all sites and depths. The along-isobath component varied substantially with the seasons; largest in fall and weakest in spring. The cross-isobath component did not vary with the season. Interestingly at all sites, there was a non-zero cross-isobath transport, which is a significant departure from standard two-dimensional descriptions of shelf circulation. The total mean depth-averaged flow was oriented nearly due west; along the mean density gradient, not along the local isobath.

Geostrophic currents were estimated from the bottom pressure and moored density observations. Subtidal current variability was highly geostrophic, particularly in the along-isobath direction, and the variability was primarily due to barotropic geostrophic fluctuations. At lower frequencies (time scales of months to seasons), baroclinic geostrophic fluctuations were important. On monthly time scales, vertical shear in the middle and lower water column were highly geostrophic, particularly for the along-isobath component. The seasonal variations in along-isobath flow were explained by seasonal changes in the geostrophic flow. Low-frequency (monthly, seasonal and mean) ageostrophic transport (the difference between the observed and geostrophic transports) balanced the Ekman transport due to the wind and bottom stress (bottom stress was much smaller than wind stress). Thus, the subtidal and lower frequency circulation are primarily a combination of geostrophic flow and wind-driven Ekman transport.

## **IMPACT/APPLICATION**

The analysis of the temperature and salinity variability provides the most complete characterization of the processes influencing stratification on the New England shelf to date. A key result potentially relevant to a broad range of shelves is the importance of the cross-shelf salinity distribution to the processes influencing the stratification.

The shift in inertial frequency caused by the subtidal relative vorticity makes possible the trapping of inertial energy over the shelf. This is potentially a mechanism for explaining the offshore increase in inertial variability.

The balance between baroclinic pressure gradient and wind stress in the depth-averaged momentum balance raises interesting possibilities for the dynamics of shelf circulation previously not considered. It highlights the fundamental importance of the density field and the advection of density by the wind-driven flow.

## **TRANSITIONS**

None

## **RELATED PROJECTS**

***Bottom Boundary Layers*** – We have been collaborating with Trowbridge to determine the dynamics of the bottom boundary layer and the relationship with the interior flow. We are also collaborating with

Chapman (separate ONR funding) to determine whether there is a buoyancy-driven shutdown of the bottom stress as suggested in recent modeling work by Chapman and Lentz.

***Spatial Variability*** – We anticipate collaborating with Barth and Kosro and with Gawarkiewicz and Pickart (Primer study) to determine the influence of spatial variability in our interpretation of the moored observations.

***Hurricane Response*** – We are collaborating with H. Seim and M. Sundermeyer on the response of the shelf to Hurricane Edouard.

## REFERENCES

Lentz, S., K. Shearman, S. Anderson, A. Plueddemann, and J. Edson. The evolution of stratification over the New England shelf during the Coastal Mixing and Optics study, August 1996–June 1997. *Journal of Geophysical Research*, submitted.

Shearman, R. K. and S. J. Lentz. Current variability on the New England shelf during the Coastal Mixing and Optics experiment. Part 1: Subtidal variability. *Journal of Geophysical Research*, to be submitted.

Shearman, R. K. and S. J. Lentz. Current variability on the New England shelf during the Coastal Mixing and Optics experiment. Part 2: Tidal, inertial and high-frequency variability. *Journal of Geophysical Research*, to be submitted.